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Leland A. Carlson
Professor of Aerospace Engineering
Texas A&M University
College Station, TX 77843-3141

TEXAS ENGINEERING EXPERIMENT STATION

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USER'S MANUAL FOR THE PRECURSOR SOLUTION SCHEME

(Programs: RADICAL, PREC, CHKCONV, etc.)

by

Scott A. Stanley

for

Dr. Leland A. Carlson
Aerospace Engineering Department
Texas A&M University

December 1990

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INTRODUCTION

This document describes the computer programs developed to calculate the shock wave precursor and the method of using them. This method calculates the precursor flow field in a nitrogen gas including the effects of emission and absorption of radiation on the energy and composition of the gas. The radiative transfer is calculated including the effects of absorption and emission through the line as well as the continuum processes in the shock layer and through the continuum processes only in the precursor. The effects of local thermodynamic nonequilibrium in the shock layer and precursor regions are also included in the radiative transfer calculations. Details of the formulation of this computational method are provided in the thesis by Stanley[1].

This computational scheme utilizes three computer programs to calculate the precursor flow field solution for a given shock layer flow field. The first of these programs, RADICAL, is used to calculate the radiative transfer through the flow field. This program is a modified version of a program written by Nicolet[2,3]. The second program, PREC, calculates the precursor flow field utilizing the radiative transfer results from RADICAL. In order to calculate a precursor flow field solution it is necessary to iterate between the two programs, RADICAL and PREC, to fully couple the radiative transfer and the precursor flow field. This iterative scheme will be discussed in the next section.

Finally, CHKCONV calculates the maximum change between two precursor flow field solutions. This program is used to check for convergence of the precursor flow field and the radiative transfer in the iteration between RADICAL and PREC.

There are also a number of programs which can be used to manipulate the output files from this solution method. These programs will be discussed in the final section of this text.

SOLUTION SCHEME

As discussed above, it is necessary to iterate between the two programs, RADICAL and PREC, in order to calculate a coupled precursor solution. This iteration is necessary since the precursor flow field is dependent on the radiative transfer and is also necessary to correctly calculate the radiative transfer.

This iteration scheme begins by first assuming a set of flow field conditions in the precursor. RADICAL is then used to calculate the radiative transfer through the entire flow field utilizing these precursor conditions along with the known shock layer conditions. These radiative transfer results are then utilized by the program PREC in the calculation of a new precursor flow field. Finally, the program CHKCONV is used to compare the new precursor flow field to the previous flow field to check for convergence. This iterative scheme is illustrated graphically in Figure 1.

Appendix A is a command file which iterates through this solution scheme five times. It has been found through numerical studies that five iterations will typically meet a convergence criteria of 0.05 percent. This command file saves all five of the precursor flow field solutions in the files prec1.dat, prec2.dat, ..., prec5.dat.

Details on the input and output files for each individual program are provided in the following sections.

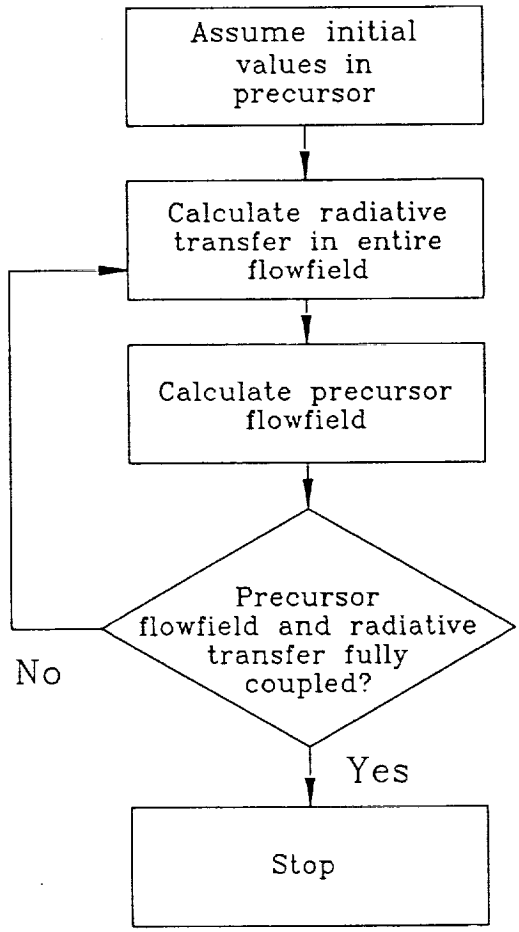

Figure 1: Precursor Iteration Scheme

RADICAL

As mentioned previously, RADICAL is a modified version of a radiative transfer program written by Nicolet[2]. In order to use this program it was necessary to modify some subroutines in order to extract the information necessary to calculate the radiative effect on the precursor flow field. Also, several radiative processes which are important in the cool nitrogen precursor have been added to those originally included in RADICAL. These modifications involved changes in the six subroutines:

contn	lint
contn2	lint2
mu	mule

and the main routine,

radical

The subroutine, addlns, was also added during these modifications.

Changes have also been made to RADICAL to include collision limiting[4] corrections for local thermodynamic nonequilibrium in the precursor region. These modifications include changes to the subroutines contn2 and mu as well as the addition of eleven subroutines:

ai3	gami
ai3a	limit
crosab	molin
exctml	parim
exctmm	taint
gamc	

It should also be noted that the dimension statements in RADICAL have been modified to allow 300 spatial points.

INPUT FILES

RADICAL reads from four input files:

fort.24	rad.dat
prec.dat	fort.3

The first two of these files, fort.24 and prec.dat, contain the shock layer and the precursor flow field conditions, respectively.

fort.24 - Shock layer flow field data, see Appendix B.

Line 1, [I5, 9E13.6]

Field 1, (Columns 1-5) JE
The number of spatial points used in the shock layer, maximum of JE + JPREC = 300.

Field 2, (Columns 6-18) S
S location around the body in the VSL solution. Not used in the precursor calculations.

Field 3, (Columns 19-31) YS(2)
Shock layer thickness nondimensionalized by the body nose radius, YS(2) = Y_{shock}/R_{nose}.

Field 4, (Columns 32-44) RNOSE
Body nose radius, R_{nose} (ft).

Field 5, (Columns 45-57) TREF
Reference temperature in the VSL nondimensionalization scheme (°R).

Field 6, (Columns 58-70) PREF
Reference pressure in the VSL nondimensionalization scheme (psi).

Field 7, (Columns 71-83) PS(2)
Nondimensional pressure immediately behind the shock, PS(2) = $P_{behind\ shock}$/PREF

Field 8, (Columns 84-96) RHOREF
Reference density in the VSL nondimensionalization scheme ($slug/ft^3$).

Field 9, (Columns 97-109) RS(2)
Nondimensional density immediately behind the shock, RS(2) = $\rho_{behind\ shock}$/RHOREF.

Field 10, (Columns 110-122) TWALL
Wall temperature for use in the radiative flux calculations (°R).

Line 2, [I5, 9E13.6]

Field 1, (Columns 1-5) NS
Number of species in gas.

Field 2, 3, ..., NS, (Columns 6-18, 19-31, etc) (EMI(j), j=1, NS)
Molecular weight of the jth species, (g/Mole). For this field, the five nitrogen species must be in the order N, N_2, N^+, e^-, N_2^+.

Line 3, 5, 7, ..., 2*JE+1, (One for each spatial location starting with the point closest to the body) [6E13.6]

Field 1, (Columns 1-13) ETA(j)
Nondimensional spatial location at the jth spatial point, ETA(j) = Y/Y_{shock}.

Field 2, (Columns 14-26) RHO(j,2)
Nondimensional density at the jth spatial point, RHO(j,2) = ρ/(RHOREF*RS(2)).

Field 3, (Columns 27-39) P(j,2)
Nondimensional pressure at the jth spatial point, P(j,2) = P/(PREF*PS(2)).

Field 4, (Columns 40-52) T(j,2)
Nondimensional temperature at the jth spatial point, T(j,2) = T/TREF.

Field 5, (Columns 53-65) TE(j)
Nondimensional electron/electronic temperature at the jth spatial point, TE(j) = T_e/TREF.

Field 6, (Columns 66-78) EMBAR(j)
Molecular weight of the gas at the jth spatial point, (g/Mole).

Line 4, 6, 8, ..., 2*JE+2, (One for each spatial location starting with the point closest to the body) [12E13.6]

Field 1, 2, ..., NS, (Columns 1-13, 14-26, etc) (CC(j,2,k), k=1, NS)
Mass fraction for the kth species at the jth spatial location, CC(j,2,k) = ρ_k/ρ. The five nitrogen species must be in the same order as the molecular weights in line 2.

prec.dat - Precursor flow field data, see Appendix C.

Line 1, [I5] JPREC
The number of spatial points used in the precursor, maximum of JE + JPREC = 300.

Line 2, 4, 6, ..., 2*JPREC, (One for each spatial location starting with the point closest to the body) [6E13.6]

Field 1, (Columns 1-13) ETA(j)
Nondimensional spatial location at the jth spatial point, ETA(j) = Y/Y_{shock}.

Field 2, (Columns 14-26) RHO(j,2)
Nondimensional density at the jth spatial point, RHO(j,2) = ρ/(RHOREF*RS(2)).

Field 3, (Columns 27-39) P(j,2)
Nondimensional pressure at the jth spatial point, P(j,2) = P/(PREF*PS(2)).

Field 4, (Columns 40-52) T(j,2)
Nondimensional temperature at the jth spatial point, T(j,2) = T/TREF.

Field 5, (Columns 53-65) TE(j)
Nondimensional electron/electronic temperature at the jth spatial point, TE(j) = T_e/TREF.

Field 6, (Columns 66-78) EMBAR(j)
Molecular weight of the gas at the jth spatial point, (g/Mole).

Line 3, 5, 7, ..., 2*JPREC+1, (One for each spatial location starting with the point closest to the body) [12E13.6]

Field 1, 2, ..., NS, (Columns 1-13, 14-26, etc) (CC(j,2,k), k=1, NS)
Mass fraction for the kth species at the jth spatial location, CC(j,2,k) = ρ_k/ρ. The five nitrogen species must be in the same order as the molecular weights in line 2.

rad.dat - Permanent and case specific data for the radiation calculations. Details of this input file are presented in reference 3 and an example of this file is shown in Appendix D. Changes to the description in reference 3 are as follows.

DECK B - CASE DATA
Group 1 - Control Card and Title

Card 1, [20I1, 15A4]

Field 1, (Columns 1-20) KR

.
.
.

Column 14 - Determines whether local thermodynamic nonequilibrium corrections are used in the shock layer.

0 - No LTNE corrections
1 - Using LTNE corrections

Column 15 - Determines whether local thermodynamic nonequilibrium corrections are used in the precursor.

0 - No LTNE corrections
1 - Using LTNE corrections

.
.
.

fort.3 - Species excited state data and transition cross sections used in calculating collision limiting LTNE correction factors in the precursor region.

OUTPUT FILES

radical.out - Detailed output from the radiative transfer calculations. A discussion of this output is given in reference 3.

fort.55 - Precursor flow field properties for input into the program PREC. NOTE: This is an unformatted file and can not be printed or viewed on the screen.

fort.56 - Spectrally detailed data from the radiative transfer calculations for input into the program PREC. NOTE: This is an unformatted file and can not be printed or viewed on the screen.

PREC

The program, PREC, utilizes the results of the radiative transfer calculations by RADICAL and calculates the flow field conditions in the precursor. This program treats the precursor as a nitrogen gas and includes the effects of chemical as well as thermal nonequilibrium. Thermal nonequilibrium is accounted for in this program through the inclusion of an electron/electronic temperature and appropriately an electron/electronic energy equation. A variable spatial step size is also utilized to force the property changes between each spatial point to remain within user provided limits. A detailed discussion of this precursor model and the solution scheme used in this program is provided in reference 1.

INPUT FILES

prec.inp - Thermodynamic data for the precursor calculations. An example of this input file is provided in Appendix E.

Line 1, [A5] Dummy line, not used.

Line 2, [E12.4] DH
Planck's constant, (erg-sec).

Line 3, [E12.4] R
Universal gas constant, (erg/(Mole °K)).

Line 4, [E12.4] AV
Avogadro's number, (1/Mole).

Line 5, [E12.4] C
Speed of light, (cm/sec).

Line 6, [A5] Dummy line, not used.

Line 7, [E12.4] VIN
Freestream velocity, (cm/sec).

Line 8, [E12.4] RBODY
Body radius, (cm).

Line 9, [E12.4] YSHOCK
Shock standoff distance, (cm).

Line 10, [I2] NCORR

Radiation correction flag, specifies which method, if any, should be used to account for the geometric attenuation of the radiation in the precursor, see Appendix C of reference 1.

0 - No geometric attenuation
1 - Include geometric attenuation using body attenuation factor
2 - Include geometric attenuation using shock layer attenuation factor

Line 11, [I2] NDBG

Debug flag, specifies whether extended files are created to aid in debugging problems in the code.

0 - No extended output
1 - Create extended output

Using the "1" option for this flag creates six files in addition to the standard output files.

fort.15 - Contains the mass production rate for each species at each spatial location. The first column contains the spatial location and the following five columns are the production rates for the five species: N, N_2, N^+, e^-, N_2^+.

fort.16 - Contains the values for the terms on the right hand side of the electron/electronic energy equation. These terms are in the order of the terms in equation (7) of reference 1 where the last two terms have been combined.

fort.18 - Contains detailed output of the temperature and the mass fractions during the iteration at each spatial location.

fort.19 - Contains details about the integral terms on the right hand side of the electron/electronic energy equation and the portions of these terms due to each individual molecular band.

fort.75 - Contains the spatial and frequency variation of the geometric attenuation factors.

fort.76 - Contains the spatial and frequency variations of the total absorption coefficient.

Line 12, [A5] Dummy line, not used.

Line 13, [A5] Dummy line, not used.

Line 14, [I2] NS
Number of species.

Line 15, 21, ..., 9+NS*6, [A5] SPECSYM(i)
Periodic symbol for the ith species.

Line 16, 22, ..., 10+NS*6, [3E10.4]
Field 1, (Columns 1-10) MW(i)
Molecular weight for the ith species, (g/Mole).

Field 2, (Columns 11-20) EION(i)
Ionization energy for the ith species, (ev).

Field 3, (Columns 21-30) EDISS(i)
Dissociation energy of the ith species, (ev).

Line 17, 23, ..., 11+NS*6, [3F8.4]
Field 1, (Columns 1-8) TRAROT(i)
Constant for the translational/rotational energy relation. Ie.

3/2 for N
5/2 for N_2

Field 2, (Columns 9-16) THTVIBR(i)
Characteristic temperature of vibration for the ith species, (°K).

Field 3, (Columns 17-24) EZERO(i)
Zero point energy of the ith species, (ev).

Line 18, 24, ..., 12+NS*6, [I2] NEL(i)
Number of electronic levels included in the electronic energy term for the ith species.

Line 19, 25, ..., 13+NS*6, [10F10.4]
Field 1, 2, ..., NEL(i), (Columns 1-10, 11-20, etc)
(DEG(i,j), j=1, NEL(i))
Degeneracy for the jth electronic state of the ith species.

Line 20, 26, ..., 14+NS*6 [10F10.4]
Field 1, 2, ..., NEL(i), (Columns 1-10, 11,20, etc)
(THTEL(i,j), j=1, NEL(i))
Characteristic temperature for the jth electronic state of the ith species, (°K).

Line 15+NS*6, [A5] Dummy line, not used.

Line 16+NS*6, [A5] Dummy line, not used.

Line 17+NS*6, [I3] NCOL
Number of sets of collision cross section data included below.

Line 18+NS*6, 19+NS*6, ..., 17+NS*6+NCOL, [2I2, 2F10.4]
Field 1, (Columns 1-2) NS1
Number for the first species involved in the reaction associated with the following collision cross section data. NOTE: NS1 < NS2.

Field 2, (Columns 3-4) NS2
Number for the second species involved in the reaction associated with the following collision cross section data.
NOTE: NS1 < NS2.

Field 3, (Columns 5-14) VLG2000
Value of the logrithm_{10} of the collision cross section at 2000°K.
NOTE: This program assumes the collision cross sections are given as a linear variation of the logrithm_{10} of the cross section as given in Gnoffo, Gupta and Shinn[5].

Field 4, (Columns 15-24) VLG4000
Value of the logrithm_{10} of the collision cross section at 4000°K.

prec.conv - Convergence criteria for the precursor calculations. An example of this file is shown in Appendix E.

Line 1, [3(F6.4, 1X), I1, 1X, F6.4]
Field 1, (Columns 1-6) VLCONV
Convergence criteria for the local iteration at each point in the precursor expressed as a maximum fractional change. Ie.

$$\frac{(V^{n+1} - V^n)}{V^n} \leq VLCONV$$

Field 2, (Columns 8-13) DELMX
Maximum fractional change between each spatial point for the variable spacing.

Field 3, (Columns 15-20) DELMN
Minimum fractional change between each spatial point for the variable spacing.

Field 4, (Column 22) NELCT
Flag controlling thermal nonequilibrium.

0 - Thermal equilibrium
1 - Thermal nonequilibrium

Field 5, (Columns 24-29) DAMP
Not used in this program.

fort.55 - Precursor flow field properties from previous iteration. This file is created by the program RADICAL. NOTE: This is an unformatted file and can not be printed or viewed on the screen.

fort.56 - Spectrally detailed data from the radiative transfer calculations created by the program RADICAL. NOTE: This is an unformatted file and can not be printed or viewed on the screen.

OUTPUT FILES

fort.11 - Precursor flow field conditions in a form suitable for input into a graphing program.

Line 1, 2, ..., [14(E16.9, 1X)]
Field 1, (Columns 1-16) ETAS(k)
Nondimensional spatial distance from the body, Y/Y_{shock}.

Field 2, (Columns 18-33) QTOTS(K)
Radiative flux corrected for the geometric attenuation, (W/cm^2).

Field 3, (Columns 35-50) VELOS(k)
Velocity, (cm/sec).

Field 4, (Columns 52-67) TEMPS(k)
Heavy particle temperature, (°K).

Field 5, (Columns 69-84) PRESS(k)
Pressure, (dyn/cm^2).

Field 6, (Columns 86-101) DENSS(k)
Density, (g/cm^3).

Field 7, (Columns 103-118) EE
Electron/electronic energy, (erg/g).

Field 8, (Columns 120-135) PHTS(k)
Total enthalpy, (erg/g).

Field 9, (Columns 137-152) MASFS(1,k)
N mass fraction.

Field 10, (Columns 154-169) MASFS(2,k)
N_2 mass fraction.

Field 11, (Columns 171-186) MASFS(3,k)
N^+ mass fraction.

Field 12, (Columns 188-203) MASFS(4,k)
e^- mass fraction.

Field 13, (Columns 205-220) MASFS(5,k)
N_2^+ mass fraction.

Field 14, (Columns 222-237) TES(k)
Electron/electronic temperature, (°K).

prec.dat - Precursor flow field data in the format suitable for input into the program RADICAL. The format of this file follows that given for the input file by this name under the program RADICAL.

CHKCONV

This program reads two sets of precursor flow field data and calculates the maximum change in each flow field variable and creates an output file with this iteration data. If the maximum fractional change is less than an input global convergence criteria then a file, "converged", is created indicating that a converged precursor solution has been obtained.

INPUT FILES

prec.conv - This file contains the global iteration number and convergence criteria. An example of this file is given in Appendix F.

Line 1, [3(F6.4, 1X), I1, 1X, 2(F6.4, 1X), I2]

Field 1, (Columns 1-6) VLCONV
Not used in this program.

Field 2, (Columns 8-13) DELMX
Not used in this program.

Field 3, (Columns 15-20) DELMN
Not used in this program.

Field 4, (Column 22) NELCT
Not used in this program.

Field 5, (Columns 24-29) DAMP
Damping coefficient for the changes in the electron/electronic temperature between each iteration. Ie.

$$T_e^{n+1} = T_e^n + \left(T_e^{n+1} - T_e^n\right) DAMP$$

Field 6, (Columns 31-36) GCONV
Global convergence criteria in maximum fractional change allowed for convergence. This is applied to all flow field variables.

Field 7, (Columns 38-39) NIT
Global iteration number. Each time CHKCONV is executed this number is incremented by one.

prec.dat - Current precursor flow field properties. This file is in the same format as the input file by the same name under the program RADICAL.

prec.dat.old - Precursor flow field properties from the previous global iteration. This file is in the same format as the file "prec.dat" above. It should be noted that this file should be copied from the "prec.dat" file immediately prior to running PREC since this program creates a new "prec.dat" file, see Appendix A.

OUTPUT FILES

prec.conv - This file contains the global convergence criteria and the global iteration number; it is identical to the input file by the same name except the iteration number is incremented by one.

prec.dat - This file contains the output precursor flow field conditions and is identical to the input file, "prec.dat", except that the damping coefficient has been applied to the change in the electron/electronic temperature as discussed under the input file, "prec.conv".

preciter.out - This file contains the iteration information regarding the maximum change in each of the flow field properties through each global iteration. An example of this file is shown in Appendix G.

converged - This file is created when a converged precursor solution is obtained. It contains the iteration number on which convergence was obtained and each successive iteration number following convergence.

MISCELLANEOUS TOOLS

The four programs described in this section are tools which were developed to help work with the precursor codes. One of these programs creates an input "prec.dat" file for beginning a precursor solution and the remaining three programs extract useful data from the unformatted files, "fort.55" and "fort.56".

MKPRECIN - This program prompts the user for the freestream conditions, the number of spatial points desired in the precursor, the desired spatial extent of the precursor data file in terms of Y/Y_{shock} as well as the reference and shock conditions from the first line of the "fort.24" file. It then creates an output file, "prec.dat.save", which has the proper freestream conditions and is in the format for use as an initial "prec.dat" file to begin a precursor solution. This file, however, should be edited by hand and more points should be added near the shock. Appendix C shows an initial "prec.dat" file with a suitable distribution of spatial points near the shock.

Input Data

JPREC - Number of spatial points in the precursor.
ETAMAX - Maximum Y/Y_{shock} value desired in "prec.dat" file.

Freestream Conditions

T - Freestream temperature, (°K).
ρ - Freestream density, (g/cm^3).

Reference Conditions

Same as given in discussion of "fort.24" input file under the program RADICAL.

RFREQ - This program reads the "fort.55" and "fort.56" files and creates a file, "freq.dat", containing the spectral variation of the radiative flux at up to ten user selected spatial points in the precursor.

RFREQX - This program reads the "fort.55" and "fort.56" files and creates a file, "freq.dat", containing the spatial variation of the radiative flux in the precursor at up to fifteen frequencies selected by the user.

RDELQALL - This program reads the "fort.55" and "fort.56" files and creates an output file, "fort.81", which contains the change in the radiative flux, Δq_ν, between each spatial point for all frequencies. This is useful since the sign of this value indicates whether absorption or emission occurs. If the sign is positive, absorption occurs between the two spatial points at the particular frequency. If the sign is negative, emission occurs.

REFERENCES

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3. Nicolet, W.E., "User's Manual for the Generalized Radiation Transfer Code (RAD/EQUIL)", NASA-CR-116353, Oct. 1969.

4. Horton, T.E., "Radiative Coupled Nonequilibrium Flow Fields Associated with Aeroassisted Orbital Transfer", Final Contractors Report, NASA Grant NAG-1-496, March 1986.

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APPENDIX A: command file

```
#
radical
mv radical.out rad.out
mv prec.dat prec.dat.old
prec
mv fort.11 prec1.dat
chkconv

radical
mv radical.out rad.out
mv prec.dat prec.dat.old
prec
mv fort.11 prec2.dat
chkconv

radical
mv radical.out rad.out
mv prec.dat prec.dat.old
prec
mv fort.11 prec3.dat
chkconv

radical
mv radical.out rad.out
mv prec.dat prec.dat.old
prec
mv fort.11 prec4.dat
chkconv

radical
mv radical.out rad.out
mv prec.dat prec.dat.old
prec
mv fort.11 prec5.dat
chkconv
```

APPENDIX B: fort.24

```
  51 0.000000E+00 0.315174E-01 0.754600E+01 0.443041E+06 0.742185E+00 0.874496E+00 0.387860E-07
0.795348E+01 0.670367E-02
   5 0.140200E+02 0.280400E+02 0.140200E+02 0.548600E-03 0.280400E+02
 0.000000E+00 0.308872E+02 0.112838E+01 0.670367E-02 0.670367E-02 0.138912E+02
 0.986031E+00 0.312954E-02 0.108388E-01 0.424125E-06 0.179520E-06
 0.508404E-02 0.128738E+02 0.112834E+01 0.160825E-01 0.160881E-01 0.138907E+02
 0.986011E+00 0.312113E-02 0.108669E-01 0.425222E-06 0.179593E-06
 0.106765E-01 0.102332E+02 0.112834E+01 0.202268E-01 0.202345E-01 0.137622E+02
 0.977474E+00 0.252945E-02 0.199951E-01 0.782415E-06 0.599138E-06
 0.168282E-01 0.873712E+01 0.112834E+01 0.236824E-01 0.236917E-01 0.136094E+02
 0.967082E+00 0.182671E-02 0.310885E-01 0.121651E-05 0.115785E-05
 0.235950E-01 0.774400E+01 0.112834E+01 0.267116E-01 0.267222E-01 0.134402E+02
 0.955060E+00 0.119887E-02 0.437376E-01 0.171148E-05 0.178235E-05
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APPENDIX C: prec.dat

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0.000000E+00 0.100000E+01 0.000000E+00 0.000000E+00 0.000000E+00
0.190240E+03 0.125733E+00 0.239524E-03 0.733950E-03 0.733950E-03 0.280140E+02
0.000000E+00 0.100000E+01 0.000000E+00 0.000000E+00 0.000000E+00
0.200200E+03 0.125733E+00 0.239524E-03 0.733950E-03 0.733950E-03 0.280140E+02
0.000000E+00 0.100000E+01 0.000000E+00 0.000000E+00 0.000000E+00
0.210160E+03 0.125733E+00 0.239524E-03 0.733950E-03 0.733950E-03 0.280140E+02
0.000000E+00 0.100000E+01 0.000000E+00 0.000000E+00 0.000000E+00
0.220120E+03 0.125733E+00 0.239524E-03 0.733950E-03 0.733950E-03 0.280140E+02
0.000000E+00 0.100000E+01 0.000000E+00 0.000000E+00 0.000000E+00
0.230080E+03 0.125733E+00 0.239524E-03 0.733950E-03 0.733950E-03 0.280140E+02
0.000000E+00 0.100000E+01 0.000000E+00 0.000000E+00 0.000000E+00
0.240040E+03 0.125733E+00 0.239524E-03 0.733950E-03 0.733950E-03 0.280140E+02
0.000000E+00 0.100000E+01 0.000000E+00 0.000000E+00 0.000000E+00
0.250000E+03 0.125733E+00 0.239524E-03 0.733950E-03 0.733950E-03 0.280140E+02
0.000000E+00 0.100000E+01 0.000000E+00 0.000000E+00 0.000000E+00
```

APPENDIX D: rad.dat

```
2056
  0.40  +01   0.10  +02   0.60  +01   0.18  +02   0.54  +02   0.90  +02
  0.00  +00   0.00  +00   0.90  +01   0.50  +01   0.10  +01   0.50  +01
  0.30  +01   1.50  +01   0.90  +01   0.40  +02   0.90  +01   0.50  +01
  0.10  +01   0.50  +01   0.12  +02   0.15  +02   0.36  +02   0.00  +00
  0.20  +01   0.80  +01   0.18  +02   0.32  +02   0.00  +00   0.00  +00
  0.00  +00   0.00  +00   0.90  +01   0.00  +00   0.00  +00   0.00  +00      0
  0.00  +00   0.00  +00   0.00  +00   0.00  +00   0.40  +01   0.00  +00
  0.00  +00   0.00  +00   0.00  +00   0.00  +00   0.00  +00   0.00  +00
  0.60  +01   0.00  +00   0.00  +00   0.00  +00   0.00  +00   0.00  +00
  0.00  +00   0.00  +00   0.00  +00   0.00  +00   0.00  +00   0.00  +00
  0.00  +00   0.2384+01   0.3576+01   0.1045+02   0.1188+02   0.1300+02
  0.00  +00   0.00  +00   0.96  -02   0.1967+01   0.4189+01   0.9144+01
  0.9519+01   0.1074+02   0.1099+02   0.1208+02   0.00  +00   1.2639+00
  2.6839+00   4.1825+00   7.5351+00   7.9461+00   8.6442+00   0.00  +00      0
  0.00  +00   0.1020+02   0.1208+02   0.1274+02   0.00  +00   0.00  +00


  0.60  +00   0.85  +00   0.96  +00   0.12  +01   0.14  +01   0.162 +01
  0.24  +01   0.34  +01   0.62  +01   0.80  +01   0.86  +01   0.90  +01
  0.97  +01   0.1045+02   0.1080+02   0.1170+02   0.1210+02   0.1280+02
  0.1340+02   0.1380+02   0.00  +00   0.00  +00   0.00  +00   0.00  +00
  0.80  +00   0.95  +00   0.12  +01   0.14  +01   0.16  +01   0.24  +01
  0.3340+01   0.40  +01   0.80  +01   0.86  +01   0.90  +01   0.97  +01
  0.1045+02   0.1080+02   0.1170+02   0.1210+02   0.1280+02   0.1340+02
  0.1380+02   0.1450+02   0.00  +00   0.00  +00   0.00  +00   0.00  +00
  0.69  +00   0.89  +00   0.1080+01   0.1290+01   0.1460+01   0.1850+01
  0.2850+01   0.3700+01   0.7110+01   0.8302+01   0.8781+01   0.94  +01
  0.1007+02   0.1062+02   0.1120+02   0.1190+02   0.1241+02   0.1304+02
  0.1358+02   0.1420+02     .    +      .    +      .    +      .    +
 3 4 5 4 4 4 3 2 1 1 1 4 5 6 7 7 7 3 3 4
16          0.685       0.196          110E-21 6.
 6          0.689       0.1597         187E-20 6.
 5          0.7525      0.0149         446E-21
 5          0.875       0.0366         380E-21 4.
15         0.8840      0.1570         367E-21
 4          0.9158      0.00847        739E-22
 6          0.9304      0.0253         387E-20 2.
 6          0.965       0.0262         387E-20 4.
16          0.991       0.0805         309E-20 2.
 5          1.0355      0.0735         331E-21 7.
15         1.0980      0.7490         344E-21
14         1.1320      0.2010         367E-21
 5          1.2610      0.118          312E-21 3.
 4          1.3190      0.1833         984E-22
14         1.3380      0.9130         342E-21
 5          1.3677      0.0387         292E-21
 4          1.4380      0.256          824E-22 3.
13         1.4670      0.9500         865E-22
 5          1.5527      0.0030         293E-20
12         1.594       1.0300         709E-22
 4          1.6630      0.0923         958E-22
15          1.767       0.0226         275E-20 3.
 5          1.8357      0.00566        293E-20 5.
14          2.015      0.0258         275E-20 3.
 4          2.925       0.0070         106E-20 3.
13          3.0         0.010          810E-21 2.
12          3.167       0.00826        520E-21
 4          3.4724      0.00861        452E-20 3.
12         3.7110      0.0143         110E-20
 3         07.111      0.0634         912E-22                6.
 2         08.302      0.0740         912E-22                 6.
 3         08.781      0.0435         661E-22
 3         09.301      0.0166         446E-21
 3         09.394      0.0119         229E-21
 3         09.460      0.0360         336E-21
09         9.5010      0.0471         548E-22
 2         09.973      0.0890         661E-22
 3         10.102      0.0374         293E-20
```

```
11          10.182      0.1510          653E-22
 1          10.332      0.1840          621E-22              12.
 3          10.418      0.0225          532E-20
 2          10.493      0.0187          446E-20
 3          10.585      0.0131          796E-20
 2          10.619      0.0533          312E-21              14.
 3          10.682      0.00819         268E-19
 3          10.757      0.00518         437E-19
10          10.761      0.1200          653E-22
 1          10.927      0.4540          161E-23              12.
11          11.007      0.0185          367E-21
 3          11.200      0.0200          446E-21
 2          11.293      0.0418          293E-20
 3          11.310      0.0254          323E-21
33          11.424      0.2260          143E-23
 2          11.609      0.0250          532E-20
 2          11.776      0.0220          796E-20
11          11.806      0.0049          145E-20
09          11.852      0.0199          367E-21
 2          11.874      0.0091          268E-19
 2          11.948      0.00575         437E-19
 3          12.000      0.0269          299E-20
09          12.067      0.0218          344E-21
11          12.160      0.0019          128E-20
 3          12.316      0.0156          696E-20
10          12.404      0.0461          653E-22
 2          12.414      0.0574          390E-21
 2          12.511      0.0279          337E-21
09          12.521      0.0775          633E-22
09          12.651      0.00524         145E-20
 1          12.877      0.0230          446E-21
 1          13.004      0.1320          294E-21              12.
 2          13.190      0.0489          299E-20
 2          13.508      0.0291          696E-19
33          13.543      0.1610          950E-24
 1          13.677      0.0957          293E-20
 1          13.993      0.0584          532E-20
 1          14.160      0.0342          796E-20
 1          14.257      0.0212          268E-19
 1          14.332      0.0138          437E-19
 74
 .02         .1          .2          .3          .49         .6
 .8          1.0         1.5         2.0         2.25        2.59
 3.0         3.5         4.0         4.43        4.5         4.76
 4.77        5.0         6.0         6.2         7.0         7.039
 7.041       8.0         8.239       8.241       8.546       8.551
 9.0         9.419       9.421       9.77        9.78        9.9
 10.0        10.15       10.3        10.45       10.6        10.79
 10.81       11.0        11.15       11.25       11.27       11.40
 11.6        11.8        11.99       12.01       12.15       12.25
 12.399      12.401      13.39       13.41       13.59       13.61
 14.29       14.3        15.0        15.58       15.59       15.7
 15.8        15.9        16.0        16.1        16.2        16.3
 16.4        16.5
10011010111201100000   FIRE II FLUX ABSORBED
01100
  1  0  1  0  0  0  0  1  0  0  0  1  0  0  0  0  0  0  0  0
1.
```

APPENDIX E: prec.inp

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
6.6256e-27                                                          - Planck's Constant
8.3143e7                                                            - Universal Gas Constant
6.023e23                                                            - Avogadro's Number
3.0e10                                                              - Speed of Light

1.6d6                                                               - Velocity
230.0                                                               - Body Radius
7.249                                                               - Shock Standoff
2                                                                   - Radiation Correction Flag
0                                                                   - Debug Flag

Species Data
 5                                                                  - Number of Species
N                                                                   - Species Symbol
14.007    14.3      0.0                                                     - MW, Eion, Ediss
1.5     0.0     4.89                                                    - TraRot, ThtVibr, Ezero
 6                                                                  - Number of Electronic Terms
4.0       10.0      6.0       18.0      54.0      90.0                      - Degeneracies
0.0       27670.0   41496.0   121300.0  137900.0  150900.0                  - Charact. Temp
N2                                                                  - Species Symbol
28.014    15.59     9.78                                                    - MW, Eion, Ediss
2.5     3390.0  0.0                                                       - TraRot, ThtVibr, Ezero
 4                                                                  - Number of Electronic Terms
1.0       3.0       6.0       2.0                                       - Degeneracies
0.0       71592.0   85343.0   99212.0                                   - Charact. Temp
N+                                                                  - Species Symbol
14.007    0.0       0.0                                                     - MW, Eion, Ediss
1.5     0.0     19.19                                                   - TraRot, ThtVibr, Ezero
 6                                                                  - Number of Electronic Terms
1.0       3.0       5.0       5.0       1.0       5.0                       - Degeneracies
0.0       70.5      188.5     22036.5   47029.68  67864.8                   - Charact. Temp
e-                                                                  - Species Symbol
5.4847e-4 0.0       0.0                                                     - MW, Eion, Ediss
1.5     0.0     0.0                                                     - TraRot, ThtVibr, Ezero
 1                                                                  - Number of Electronic Terms
1.0                                                                 - Degeneracies
0.0                                                                 - Charact. Temp
N2+                                                                 - Species Symbol
28.014    0.0       0.0                                                     - MW, Eion, Ediss
2.5     3390.0  15.59                                                     - TraRot, ThtVibr, Ezero
 4                                                                  - Number of Electronic Terms
2.0       4.0       2.0       2.0                                       - Degeneracies
0.0       13191.0   36634.0   92977.4                                   - Charact. Temp

Collision Cross Section Data (Gnoffo Linear Logrithmic Coefficients)
  4                                                 - Number of Collision Cross Section Data
 1 4 -15.3     -15.3                                - Spec#1, Spec#2, Log2000, Log4000
 2 4 -15.11    -15.02                               - Note: Spec#1 <= Spec#2 Only the
 3 4 -11.7     -12.19                               - upper triangular portion of this
 4 5 -11.7     -12.19                               - matrix is specified since it is
                                                    - symmetric
```

APPENDIX F: prec.conv

```
0.0005 0.1500 0.0100 1 1.0000 0.0050 00
```

APPENDIX G: preciter.out

```
 nit=  1  damp= 1.0000     gconv= 0.0050
          dens            press           temp            eltemp          mf
del  -.1000000E-05  -.1217500E-04  -.9600000E-06  -.1728515E-01  0.2459000E-02
pdel  .7953361E-05   .5082998E-01   .1307991E-02   .2355085E+02  Inf

 nit=  2  damp= 1.0000     gconv= 0.0050
          dens            press           temp            eltemp          mf
del  0.0000000E+00  0.8400000E-06  -.3130000E-06  0.2233700E-02  -.1300000E-04
pdel  .0000000E+00   .3362340E-02   .4259031E-03   .1410405E+00  Inf

 nit=  3  damp= 1.0000     gconv= 0.0050
          dens            press           temp            eltemp          mf
del  0.1000000E-05  -.3200000E-07  0.1190000E-06  -.6180000E-04  -.1000000E-07
pdel  .7953298E-05   .1275475E-03   .1620165E-03   .4466189E-02   .2168221E-01

 nit=  4  damp= 1.0000     gconv= 0.0050
          dens            press           temp            eltemp          mf
del  0.0000000E+00  0.2000000E-08  -.7000000E-08  0.1700000E-05  0.1000000E-07
pdel  .0000000E+00   .8274310E-05   .9531928E-05   .1225181E-03   .2498403E-03

 nit=  5  damp= 1.0000     gconv= 0.0050
          dens            press           temp            eltemp          mf
del  0.0000000E+00  -.1000000E-08  0.2000000E-08  -.1000000E-06  0.2000000E-11
pdel  .0000000E+00   .4127422E-05   .2721829E-05   .7375556E-05   .7258738E-05
```